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Title:	EM Propagation Models and Scintillation Effects
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EM Propagation Models

and Scintillation Effects

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LANL
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Transionospheric Propagation

Homogeneous Shell

- Definite top and bottom altitudes
- No variation in electron density or magnetic field

(1) Taylor expansion of refractive index ($f \gg f_p$, f_{ce}) with and without magnetic birefringence - LOS: all rays reach satellite.

(2) Two dimensional Snell's law in spherical geometry (Bourger's) - solve analytically for rays that reach satellite at each frequency.

Non-Homogeneous Shell (2D)

- Can have bottom and top altitudes, or not.
- Electron density and magnetic field vary with altitude (r) only – no gradients in other directions

(3) Two dimensional Snell's law in spherical geometry (Bourger's) – solve analytically for rays that reach satellite at each frequency, including $n_e(r)$ and $B_0(r)$ in calculation.

(4) Ray trace – WKB approximation (geometric optics). must iterate over frequency and angle.

(5) Divide ionosphere into spherical shells of constant n_e and B_0. Match boundary conditions at each shell interface.

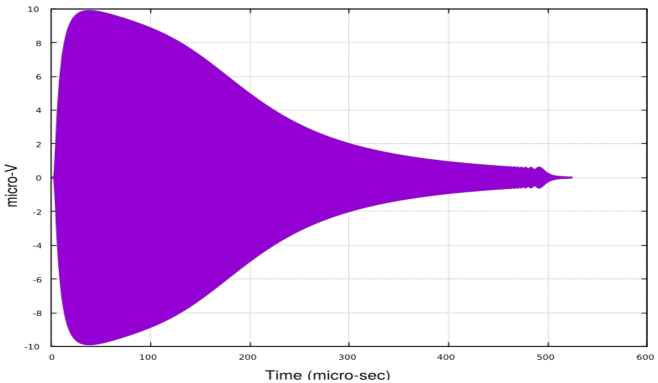
Non-Homogeneous Shell (3D)

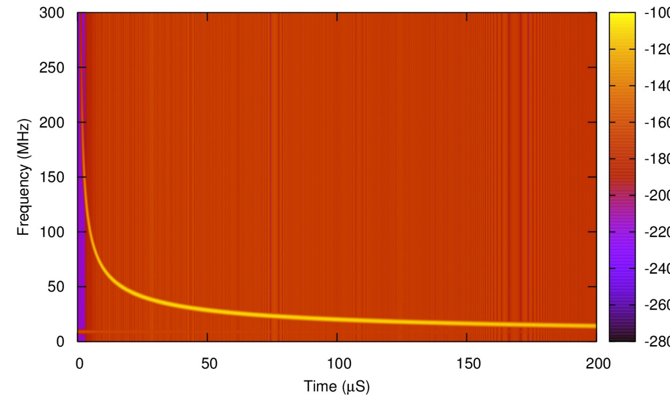
- Can have bottom and top altitudes, or not.
- Electron density and magnetic field gradients in all directions – full description of ionospheric variations.
- Horne, JGR, vol. 94, No. A7, pp. 8895 – 8909, 1989.

(6) Ray trace – WKB approximation (geometric optics). Must iterate over all launch angles and frequencies.

Transionospheric Propagation

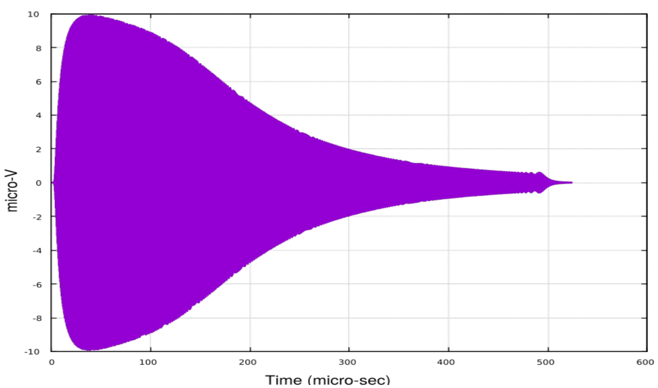
Direct LOS - No Birefrinfgence

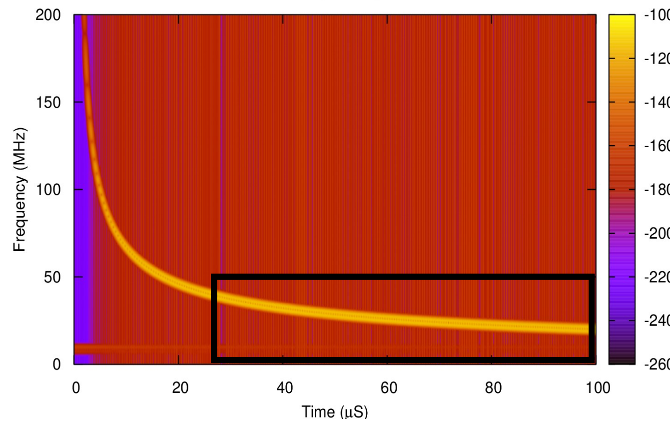


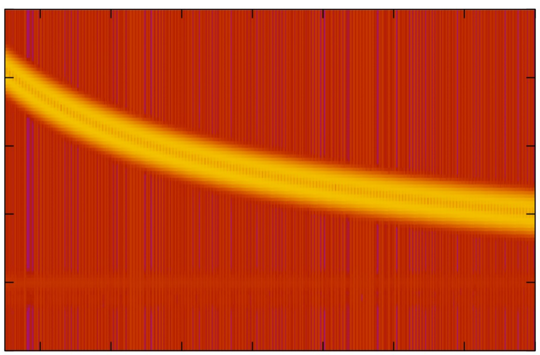


dBm / δf at Satellite

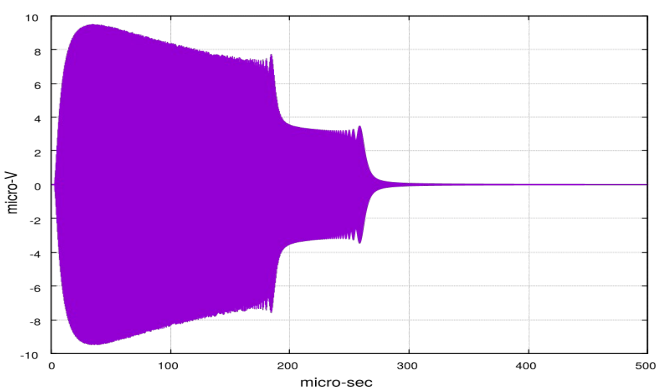
Direct LOS - Birefrinfgence

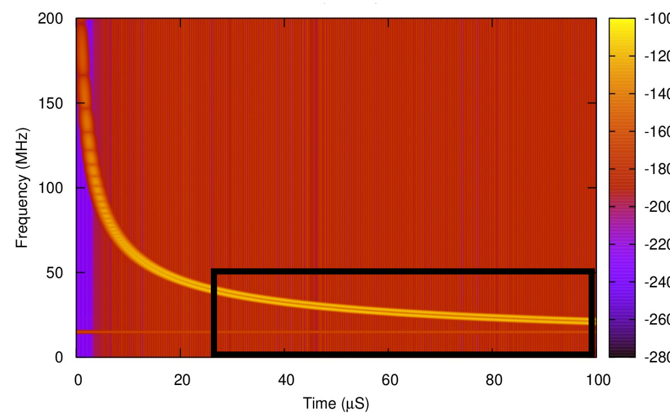


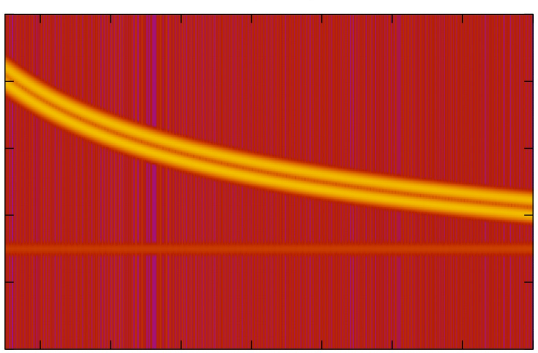




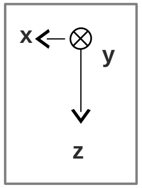
Slab - 2D ray trace







Scintillation – Multiple Phase Screen Approach



Δz

⋮

Phase Screen

$$E^{-}(x, z_0, \omega)$$

$$E^{+}(x, z_1, \omega) \rightarrow E^{+}(k_x, z_1, \omega)$$

$$E^{+}(x,\omega) = E^{-}(x,\omega)\, e^{i\phi(x)}$$

$$\phi(x) = -k \cdot \int_{-\Delta z/2}^{+\Delta z/2} \Delta\epsilon(x, z', \omega)\, dz'$$

Fresnel Propagator

$$E(x, z_2, \omega) = e^{-ik_0 z_2 - z_1} \int_{-\infty}^{+\infty} E^{+}(k_x, z_1, \omega)\, e^{i k_x^2 \frac{z_2 - z_1}{2k_0} + ik_x} d k_x$$

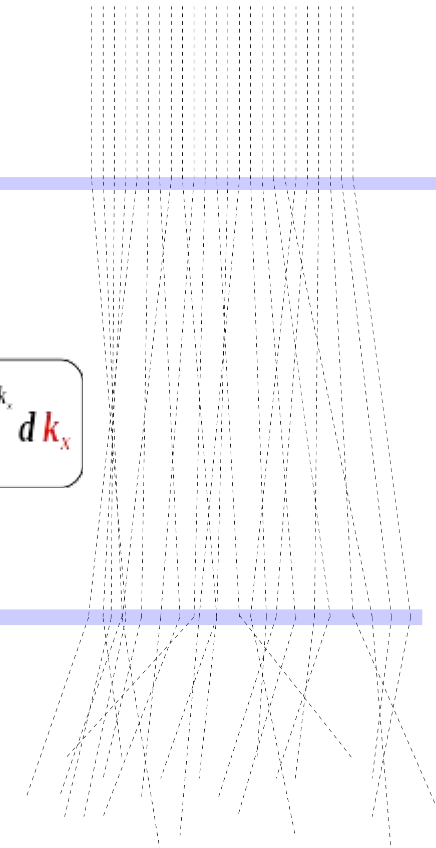
Phase Screen

$$E(k_x, z_2, \omega) \rightarrow E^{-}(x, z_2, \omega)$$

$$E^{+}(x, z_2, \omega) \rightarrow E^{+}(k_x, z_2, \omega)$$

Fresnel Propagator

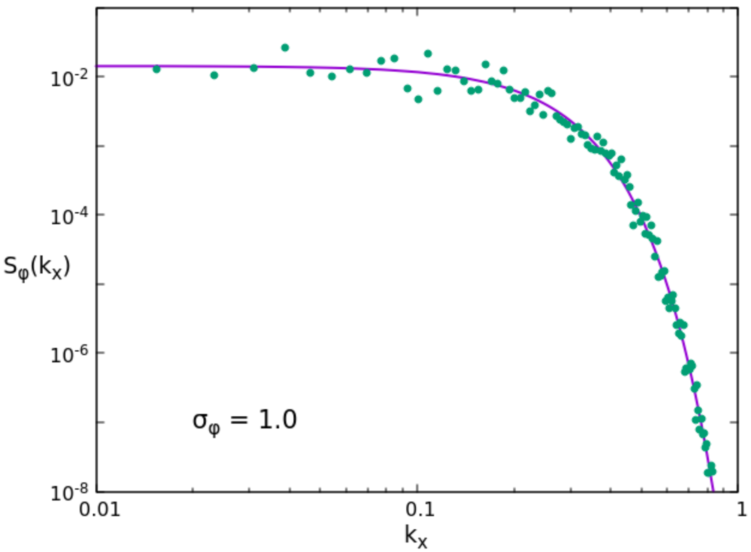
⋮



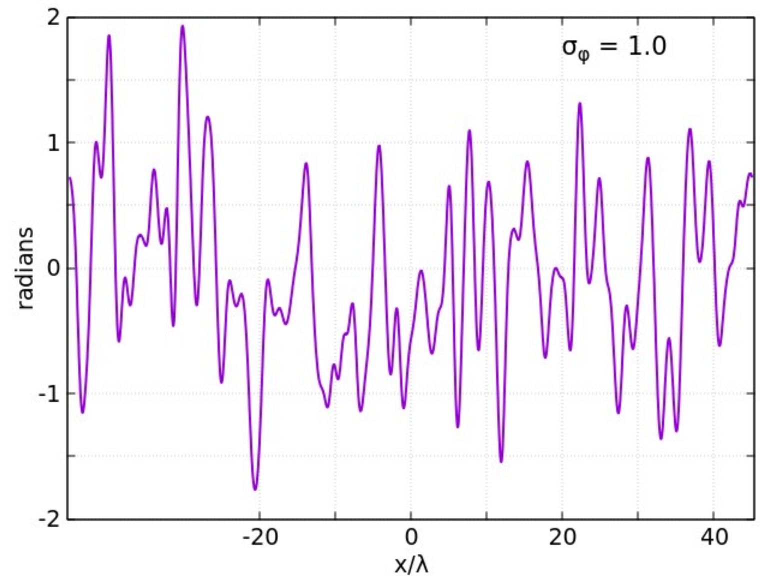
- Signal propagates through one or more thin screens
- Each screen imparts a phase contribution to the signal
- This phase is determined by the statistics of plasma density (or TEC) fluctuations
- Fresnel region can be free space or background plasma
- Implement the process by first propagating signal through a quiescent background ionosphere, and then apply phase screen(s).

Scintillation - Phase Screen Parameters Driven by TEC Fluctuation Statistics

Statistics of TEC fluctuations

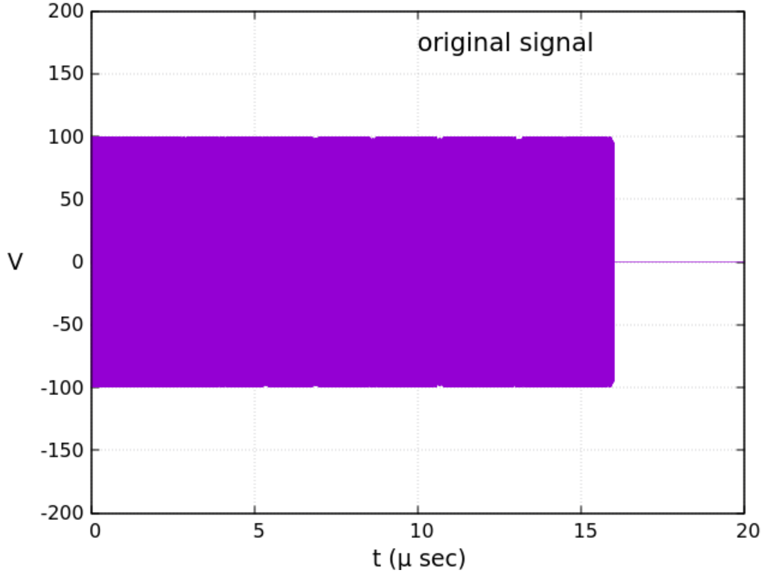


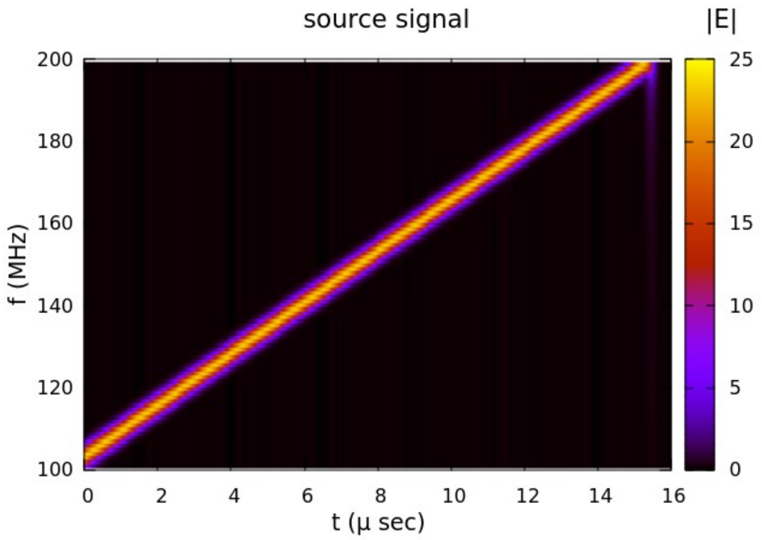
Phase Contribution Along Screen



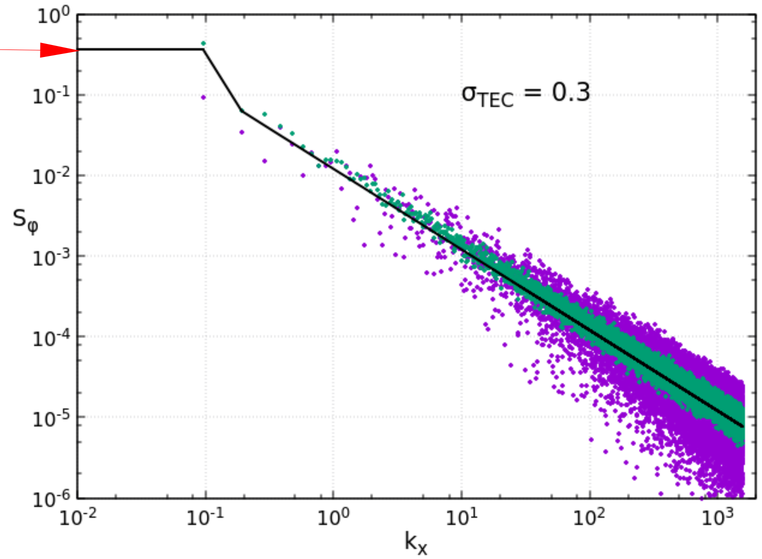
Signal Scintillation Example
Swept RF Pulse

RF Pulse swept from 100 – 200 MHz

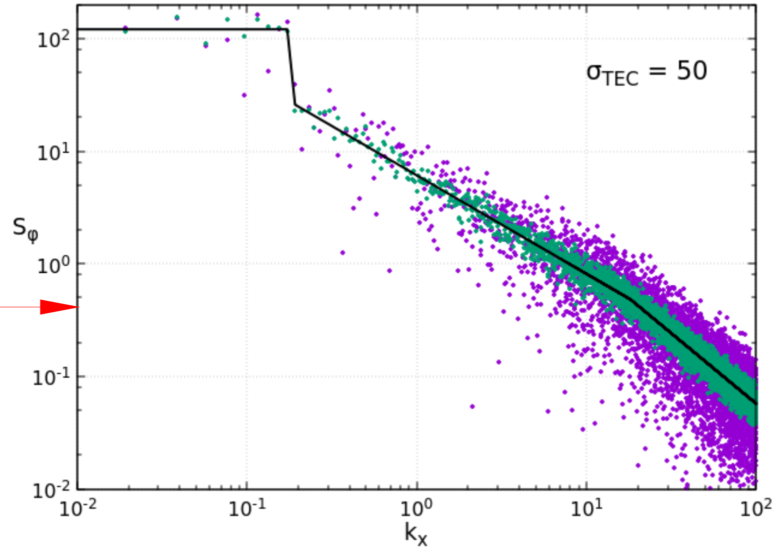




Signal Scintillation
Low and High Scintillation

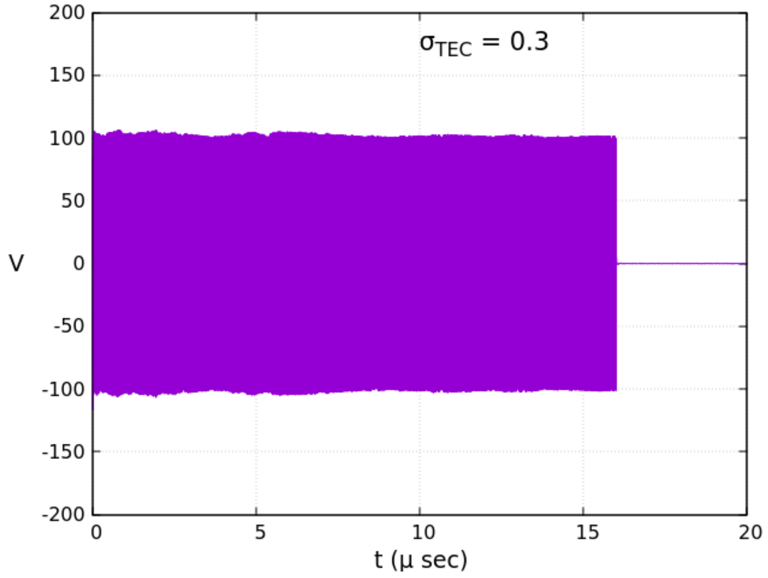


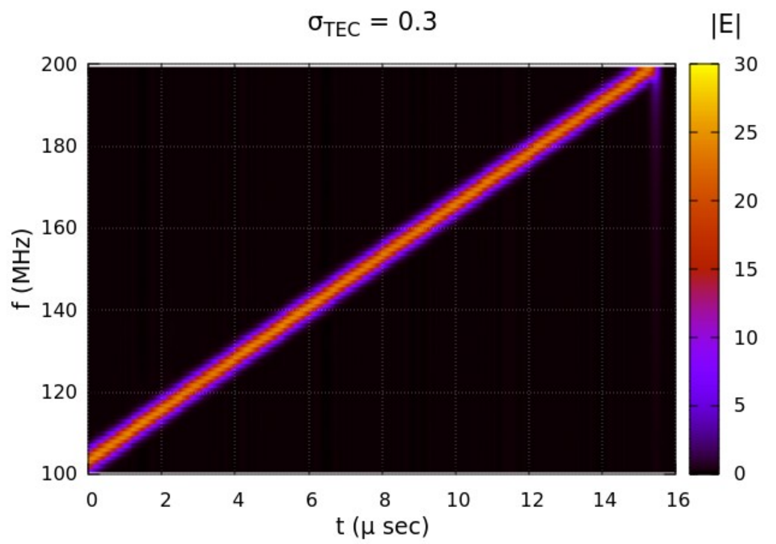
TEC variance 0.3 TECU

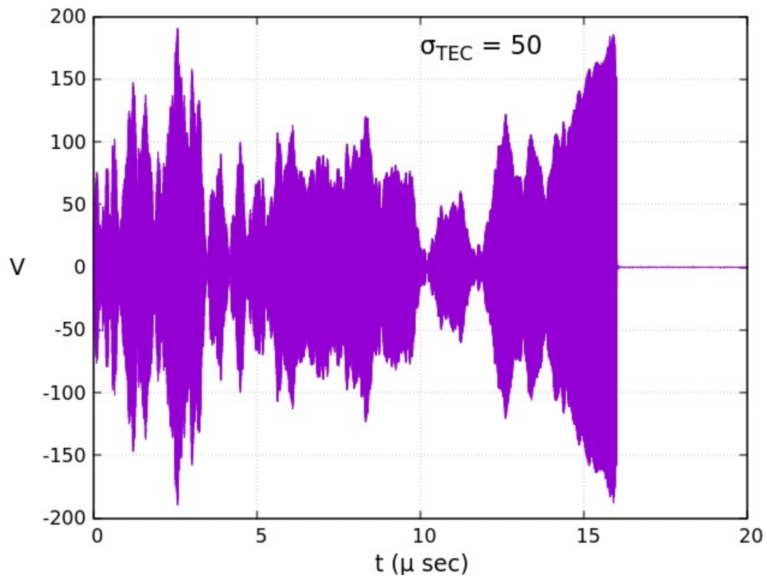


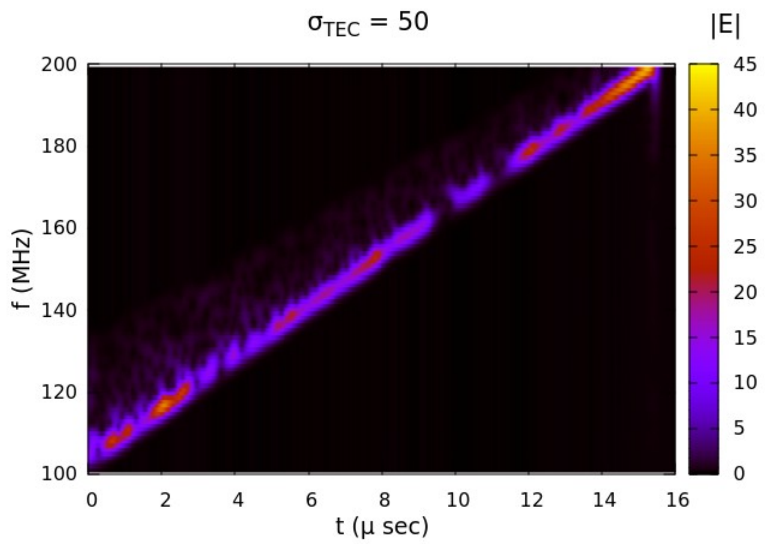
TEC variance 50 TECU

Signal Scintillation Results







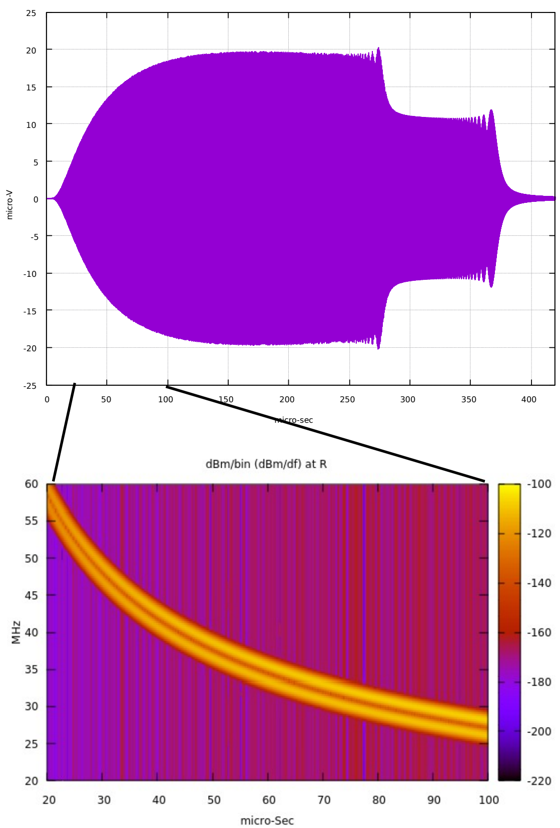


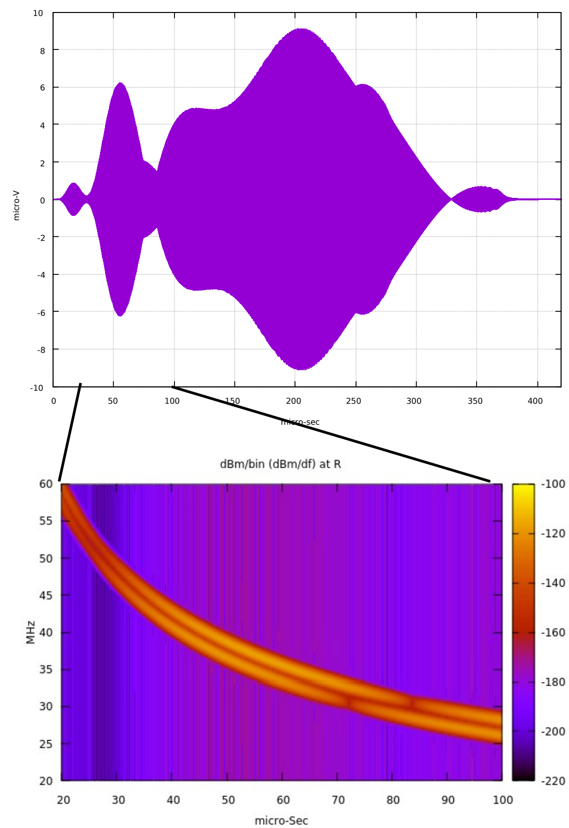
Scintillated Transionospheric Signal using MPS Model

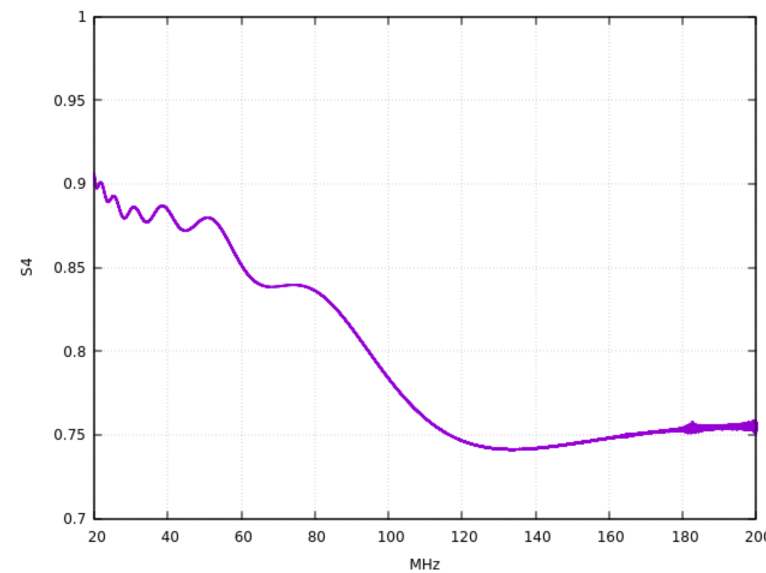
Pulse propagated through 50 TEC ionosphere using birefringent slab model.

Scintillated signal

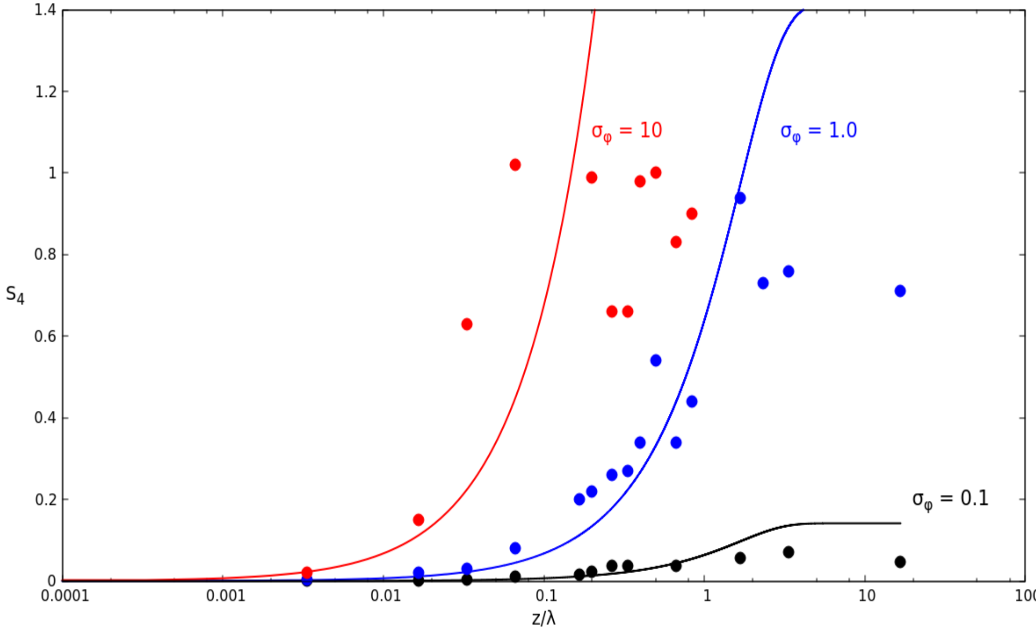
S4 over Bandwidth of Pulse



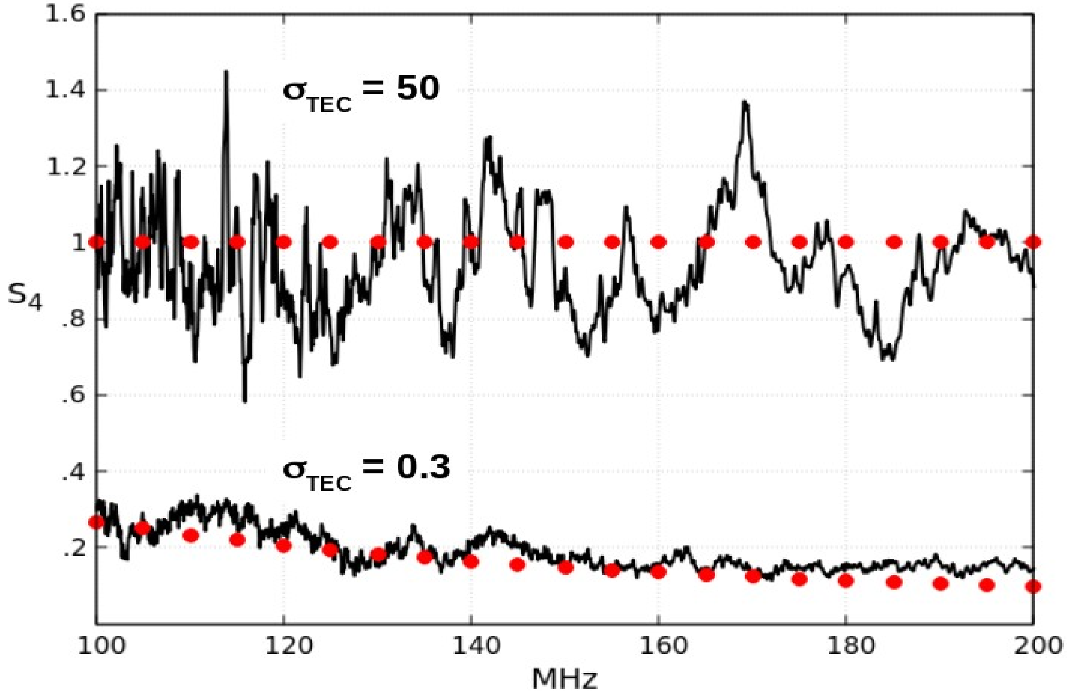




MPS Model Results
Comparison with Theory and Different Code



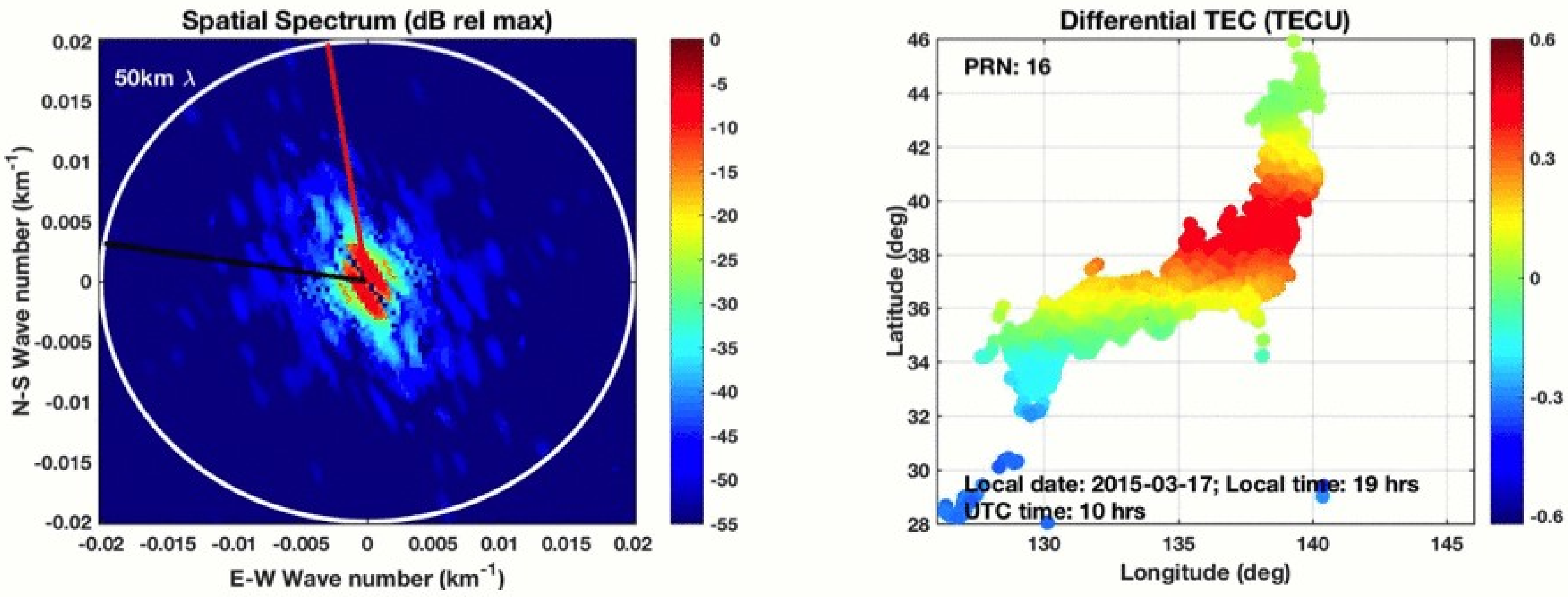
S4 vs. z/λ for different σ_ϕ
MPS results and weak scintillation theory



S4 vs. frequency for different σ_ϕ
MPS results and PRPSIM

Direct Measurement of Ionospheric disturbance k-spectrum

- **2D irregularity PSD characterization using GPS TEC receivers**



2D, 3D Ray Trace (Doppler Spread Effect)

- Chapman density profile: $n_{max} = 3\times10^{12}/m^3$, $h_{max} = 300km$
- Dipole magnetic field.
- source frequency 39.7 MHz.
- source location: lat,lon = 5^o,5^o.
- depletion/enhancement location: lat,lon = 5^o,12.5^o at 300km.
- Fast Mode